A Weak Coupling of a Nonlinear Semiconductor to the Finite Element Method

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Abstract – **The aim of this work is to present a weak coupling of a nonlinear diode model and the Finite Element Method (FEM). The coupling was accomplished by using a FEM package and HSpice, a circuit analyzer program. That coupling is applied to a time-stepping simulation of an inductor fed by a sinusoidal voltage source through a rectifier. The influence of the non-linearity is analyzed and the results are compared to other methods.**

Index Terms **– Weak Coupling, Diode, Semiconductor, Electric Circuit Coupling, Finite Element Method**

I. Introduction

One of the major achievements in the electromagnetic fields computation was the electric circuit and the finite element method coupling. Among the many benefits it brought one can point out the consideration of semiconductors in the numerical analysis.

In general, there are two different approaches to couple the Finite Element Method (FEM) with electric circuits. In the first approach, namely Strong or Direct Coupling, the equations from the FEM and the electric circuit analysis are assembled together and the system is solved simultaneously. In the second approach, known as Weak or Indirect Coupling, the FEM and the electric circuit systems are separate and the solution is achieved by an iterative method.

The aim of this work is to couple a nonlinear model of a diode with the Finite Element Method by a Weak Coupling and apply it to a Time-Stepping Finite Element Analysis of an inductor fed by a sinusoidal voltage source through a rectifier. In this work the Finite Element package used is the *Olympos* [1] and the circuit analyzer package is the *HSpice* [2].

In order to compare the influence of the non-linearity of the diodes model the simulation results were compared to the results of other three methods:

1. The FEM simulation coupled to a *On-Off* model for the diodes;
2. The simulation performed by *HSpice* only;
3. Analytical solution.

Moreover, the non-linearity is also evaluated regarding the voltage source amplitude.

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II. Diode Modeling

In this work two models for a diode are presented namely the *On-Off model* and the *nonlinear model*. For each model a Time-Stepping FEA is carried out and the results of the current are compared

On-Off Model

In the *On-Off* model the diode is considered as a perfect switch as presented in Fig. 1. No voltage drop is considered in the switch.

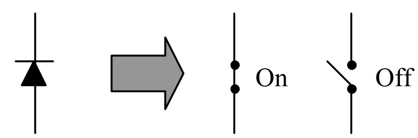
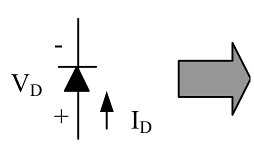


Fig. 1: On-Off Model

Nonlinear Model

The nonlinear model takes into account the nonlinear relation between the voltage and the current in the diode as presented in (1) [3].



$$V_D = V_T \ln\left(\frac{I_D}{I_S} + 1\right) + R_S I_D \qquad (1)$$

Where: V_T is the thermodynamic voltage;
I_S is the reverse saturation current;
R_S is the internal resistance.

In this work the non-linearity of the diodes is taken into account by the *HSpice* package.

III. The Problem Under Analysis

The problem under analysis consists of an inductor fed by a sinusoidal voltage source through a rectifier as shown in Fig.2.

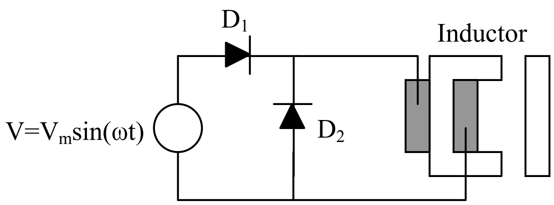


Fig. 2: FEM and Circuit Coupling Problem

The inductor has a coil with 100 turns and a linear ferromagnetic core with μ_r = 1000. The inductance and the resistance of the coil are L=13.96 mH and R=0.17 Ω, respectively.

The diodes D_1 and D_2 are modeled, in the nonlinear case, by (1) with parameters of the commercial type MBR4015 CTL [4].

The sinusoidal voltage source has amplitude of 24 V and frequency of 50 Hz.

IV. Diode Model And FEM Coupling

In order to accomplish the *Olympos* and *HSpice* weak coupling a manager is necessary to establish the file exchanging between the programs. In this work this task is done by *Matlab* [5], as presented in Fig.3.

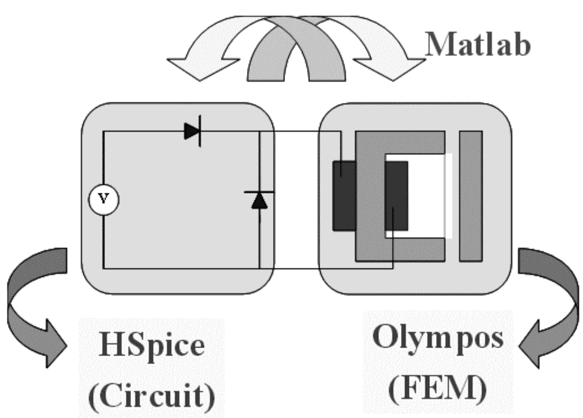


Fig. 3: Weak Coupling Scheme

The FEM provided a mesh with 342 nodes and the time-stepping analysis was carried out considering a time-step of 0.5 ms.

V. Results

Fig. 4 presents the results comparison.

Considering the results obtained from HSpice as the reference, one can observe that the numerical simulation with the nonlinear model provided results in a good agreement. It suggests that Eq.(1) represents fairly well the diode performance.

By the other hand, the results provided by the *On-Off* model indicate that this kind of modeling is not well suited in certain cases when the voltage is low.

Fig.5 shows the currents results for the analysis of the influence of the non-linearity of the diodes with higher voltages.

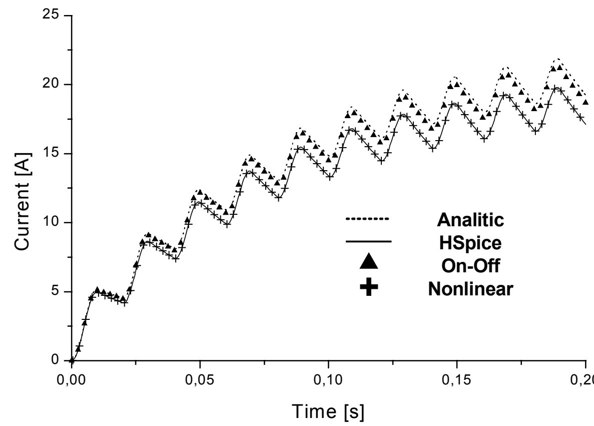


Fig. 4: Results Comparison

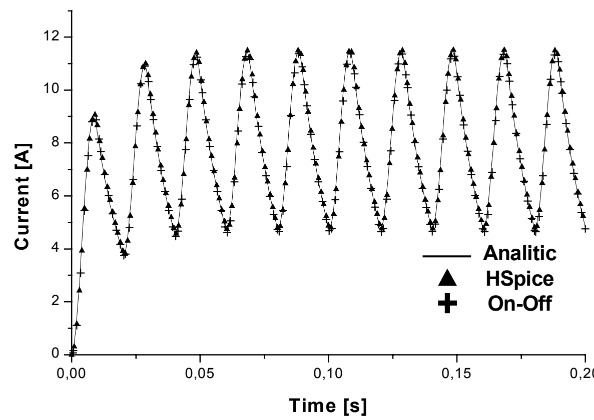


Fig. 5: Influence of the non-linearity with higher voltage

VI. Conclusions And Perspectives

A time-stepping analysis of an inductor fed by a sinusoidal voltage source through an inverter was performed. To accomplish this task a weak coupling FEM and electric circuit was proposed and a nonlinear model for the diodes was used.

In the four-page version a more detailed scheme of the weak coupling will be presented as well as an commented analysis of the influence of the non-linearity in problems with higher voltages.

References

[1] *Olympos*, Finite Element Package, ESAT/ELEN, 2001, http://www.esat.kuleuven.ac.be/elen/research/software-development

[2] *Star-HSpice*, HP platform, 2000

[3] P. Antognetti, G. Massobrio, *Semiconductor Device Modeling with SPICE*, New York, McGraw Hill, 1987.

[4] ON Semiconductors, http://www.onsemi.com

[5] *Matlab* v. 6.0, Mathworks, 2000